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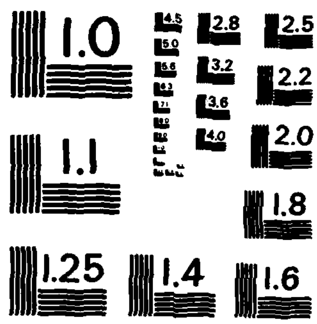

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Replication and Distribution Methods for Future TACS Distributed Databases

WILLIAM PERRIZO
DONALD A. VARVEL

31 August 1984

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This technical report has been reviewed and is approved for publication.

THOMAS SELINKA, Capt, USAF
Project Officer

SILVIO V. D'ARCO, Lt Col, USAF
Deputy Director, Tactical C^3I Systems Planning
Deputy for Development Plans

FOR THE COMMANDER

DONALD L. MILLER, Colonel, USAF
Assistant Deputy for Development Plans

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Efficient methods are needed for distributing and replicating data in a distributed information system serving military command and control functions where the loss of elements must be anticipated. Principles of distribution and replication are set forth, along with a characterization of all possible replication configurations and an investigation of some of the possibilities. The "closest neighbor" approach is investigated using both analytical and probabilistic methods. A need is identified for a replication configuration evaluator.

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for Future TACS Distributed Databases. (Unclassified)

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Replication and Distribution Methods for Future TACS Distributed Databases

William Perrizo and Donald Varvel

Efficient methods for distributing and replicating data are needed in a distributed information system serving well-structured military C^2 functions where the loss of elements must be anticipated. In future Tactical Air Control Systems, data entering at various points must be replicated to the sites where it is to be used. We recognize also that the data distribution and replication issue must be separated from the issue of functional backup site designation for C^2-elements. Functional backup site designation should be a dynamic process under the direct control of the commander. We will consider methods of data distribution and replication based on the following principles:

PRINCIPLE 1

All data needed by a site to do its current C^2 function or any future functional assignment should be sent to that site as soon as possible after it enters the system.

PRINCIPLE 2

The automated data distribution and replication method should in no way limit the commander's flexibility with respect to C^2-function assignments. The data replication site issue and the C^2-element backup site issue will be kept separate.

In this section, we begin with a mathematical model of distribution and replication methods. We will use the phrase replication configuration to mean a choice of data backup sites (primary, secondary, ...) for each site in the system. We will assume the data backup chain for a given site consists of an ordering or chaining of all other sites in the system, where the first site in the chain is designated as the primary data backup site, the second is designated as the secondary backup site, etc. We recognize that it may in some instances be unnecessary to have such a complete chain of data backup sites. The model accommodates such instances. The full chain can be truncated at the appropriate depth. However, even in the instances where full data backup seems unnecessary, if all data is prioritized, communication network idle time can be utilized to extend the data backup chain without causing adverse effects on the system. For purposes of this analysis then, we will assume a full data backup chain is to be established for each site.

It may be desirable to have several sites designated as co-primary backups (or co-secondary backups ...) rather than just one (keeping principle 2 in mind). To allow for this generality, we consider the chain of data backups for a site, a, in a system with sites, $N=\{a,b,...\}$ to be a sequence of subsets $N_{1,a}$, $N_{2,a}$,... , where $N_{1,a}$ is the set of primary data backups for a, $N_{2,a}$ is the set of secondary data backups for a, etc.

In addition to the replication configuration method, we envision a priority assignment method which will assist the network in queueing the data for transport. The details of this priority method will not be treated here, except to say that data being replicated to primary data backup sites is high priority, while data being replicated to secondary data backup sites is somewhat lower priority etc. and high priority data

is pre-emptive in communication network queues. Also, priorities will depend on the nature of the data as well as the destination.

REPLICATION CONFIGURATION FUNCTIONS

Given sets N and M, the notation N*M will be used to represent the subset of the Cartesian product with the diagonal removed (M*N = NxM-(NnM)x(NnM), where NnM is the intersection of N and M). For instance if N = {a,b,c} and M = {d,a}, then N*M = {(a,d),(b,d),(b,a),(c,d),(c,a)}. For convenience, we will always abbreviate {a}*N to just a*N. A replication configuration for a system with sites N={a,b,...} can be represented as a function, f, from N*N to the positive real numbers, R^+.

Given a replication configuration for a system with n sites, N = {a,b,...}, we will say a function f:N*N---R^+ <u>represents</u> the replication configuration if for each site, a,

$$N_{1,a}, N_{2,a}, N_{3,a}, \ldots$$

is the data backup chain for a, where $N_{1,a}$ = {b in N ¦ f(a,b) = min(f(a*N)) } , $N_{2,a}$ = {b in N ¦ f(a,b) = min(f(a*(N-$N_{1,a}$)) } , ... We will say f <u>canonically represents</u> the replication configuration if f assigns the value 1 to all primary backups, the number 2 to all secondary backups, etc. More generally, f will be called <u>canonical</u> if f:N*N--Z^+ (positive integers), and $f^{-1}(i)$ is non-empty for each i in { 1,2,...,max(f) } (that is, f assigns each integer between 1 and its max to at least 1 site).

FACT 1:

Every replication configuration is represented by one canonical function and each canonical function represents a unique replication configuration. Thus, canonical functions completely characterize replication configurations. (Recall that replication configurations with depths of 1 or 2 etc, can be derived from these by truncation.)

This fact 1 follows from the consideration that, given a replication configuration, the function which assigns 1 to all primary data backup sites, 2 to all secondary data backup sites, 3 to all third level data backup sites, etc., is canonical and that any canonical function, f, prescribes a replication configuration where the chain for site, a, is

$$N_{1,a},\ N_{2,a},\ N_{3,a},\ \ldots,\ N_{max(f),a}$$

(the sets $N_{i,a}$ are defined above).

When it is necessary to distinguish, $N_{f,i,a}$ and $N_{g,i,a}$ will be used to refer to the sets generated by the functions f and g respectively (note: f g are functions, i is a running index, and a is a site).

FACT 2

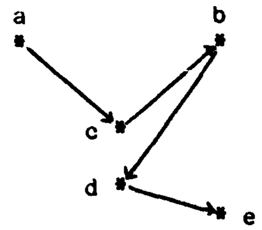
Define the relation, $R(f,g)$ if $N_{f,i,a} = N_{g,i,a}$ for every a in N and every i in $\{1,2,...\}$. The relation R is an equivalence relation which partitions all $f:N*N\text{--}R+$ into distinct classes such that each class corresponds to one configuration and contains exactly one canonical function.

This is a useful fact, for it allows us to define a configuration using any function (such as distance) without worrying about the explicit canonical function.

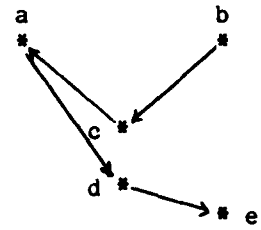
DISTRIBUTION METHODS

I. Physical distance in the theater gives us one replication configuration. Define $f(a,b)=SQRT((a_1-b_1)^2+(a_2-b_2)^2)$, where the position of site a is (a_1,a_2) in some Cartesian coordinate system. This configuration provides a separate data backup chain for each site.

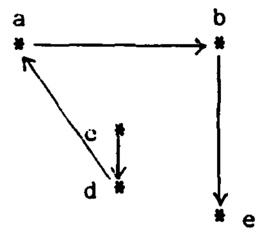
At the back of this report, the question of data backup load is studied using analytic and statistical techniques. From analytic considerations, one can conclude that the expected number of sites for which a given site will be primary data backup is 1 and the maximum number of sites for which a given site will be primary data backup is 5. Using Monte Carlo techniques, the distribution of primary data backup loads was calculated. A graph of the results of this study is included at the back of this report. The program used to produce these results is included following the graph.



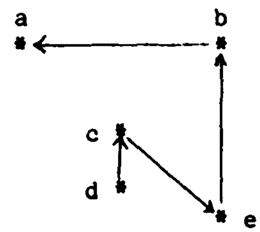
backup chain for site *a*
using physical distance



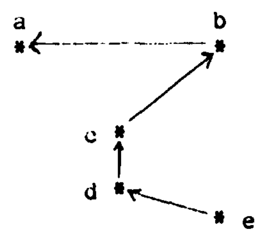
backup chain for site *b*
using physical distance



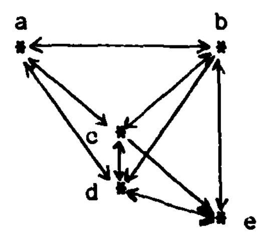
backup chain for site *c*
using physical distance



backup chain for site *d*
using physical distance



backup chain for site *e*
using physical distance



backup chains for all sites
using physical distance

figure 1

ADVANTAGES OF THE PHYSICAL DISTANCE METHOD:

1. Data backup sites are close to the backed up site itself. Therefore, for sites with area based responsibilities, the backup data could be expected to extend and enhance the resident data. In that sense it will tend to enhance the information content of the resident data.

2. It can be expected to be fairly robust under C^2-element moves over short distances, since such moves will only slightly alter the physical distance basis.

3. Backup loads are quite well distributed among the sites (see study at the back of this report).

DISADVANTAGES OF THE PHYSICAL DISTANCE METHOD:

1. The data backup capability is vulnerable to corridor attacks, due to physical proximity.

II. RECIPROCAL OF DISTANCE method, the function is $f(a,b) = 1/\text{distance}$.

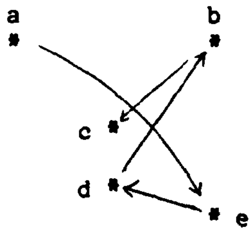
ADVANTAGES:

1. It can be expected to be immune to corridor attacks, since data backups are far removed from the site which is being backed up.

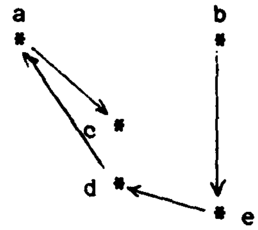
2. It can be expected to be robust under C^2-element moves over short distances, since such moves will only slightly alter physical distance and therefore the reciprocal of distance basis.

DISADVANTAGES:

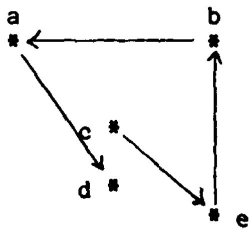
1. Backups are chosen in inverse relationship to proximity. Thus, no blending and enhancement of resident data can be expected.



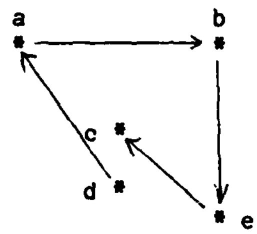
backup chain for site a
using reciprocal of distance



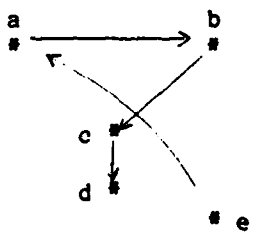
backup chain for site b
using reciprocal of distance



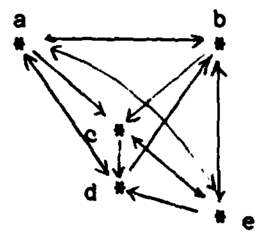
backup chain for site c
using reciprocal of distance



backup chain for site d
using reciprocal of distance



backup chain for site e
using reciprocal of distance



backup chains pattern
using reciprocal of distance

figure 2

III. CIRCULAR CHAIN METHOD:

First we enumerate the sites $N = \{a_1, a_2, \ldots\}$ according to an appropriate scheme (distance from a fixed point or random enumeration, etc.). Then we define one closed chain following that enumeration. Technically, the function is $f(a_i, a_j) = (j - i) \bmod (n)$.

ADVANTAGES:

1. The configuration is easily tuneable via the enumeration choice.

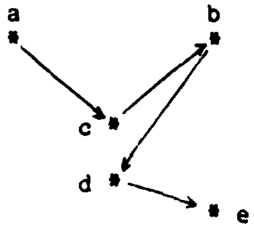
2. The class of configurations provide maximum distribution of backup loads, in the sense that each site is primary data backup for exactly one other site, each is secondary data backup for exactly one, etc.

3. It is quite easily reconfigurable, should the need arise.

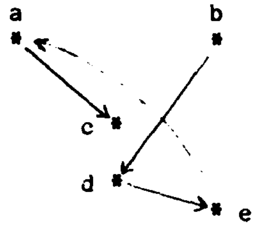
4. The data transport priority scheme can be much simpler under this replication configuration method, since each site could send data to the next site on the chain as it receives the data itself, without the necessity of considering other issues. Thus, the priority scheme might depend only upon the nature of the data itself.

DISADVANTAGES:

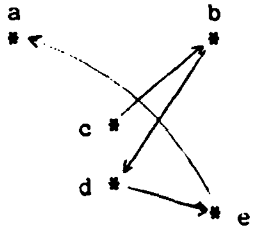
1. It may prove too simplistic for future needs.



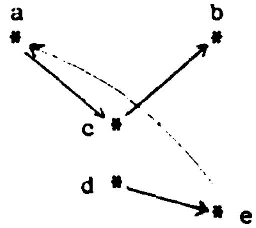
backup chain for site a
using enumeration a,c,$\overline{b}$,d,e



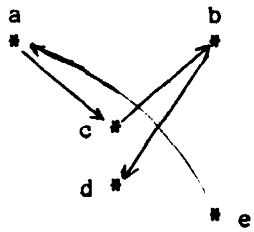
backup chain for site b
using enumeration a,c,$\overline{b}$,d,e



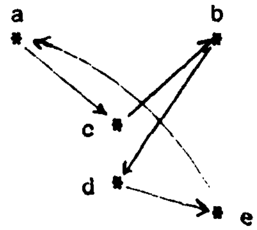
backup chain for site c
using enumeration a,c,$\overline{b}$,d,e



backup chain for site d
using enumeration a,c,$\overline{b}$,d,e



backup chain for site e
using enumeration a,c,$\overline{b}$,d,e



backup chains for all sites
using enumeration a,c,b,d,e

figure 3

IV. RANDOM METHOD:

The function, f(a,b), would involve random generation of a positive number for each pair, (a,b). This could be done allowing or disallowing two pairs to have the same number.

ADVANTAGES:

1. The method would be difficult for the enemy to decipher.

DISADVANTAGES:

1. There would be no control over such issues as backup loads, corridor immunity, etc.

V. TRUNCATED METHODS:

Primary and primary-secondary data backup sites are designated, but no further backups are designated. This can be done in conjuction with an of the above methods.

EVALUATION OF ALTERNATIVES:

Evaluation of these alternatives is needed. An evaluator might involve a simulation of the effects of battle on data backup capability. It should include considerations of the following issues:

SURVIVABILITY:

1. immunity to corridor attacks,
2. graceful degradation under attack,

3. robustness under changes in site position.

ROBUSTNESS under external change in the system.

SPEED: (assuming fixed data loads and communication network capacities)

1. time necessary to provide full primary data backup capacity,

2. time necessary to provide full secondary data backup capacity,

3. time necessary to provide full data backup capacity at all levels.

FLEXIBILITY:

1. capability for tuning and dynamic configuring,

2. ease of tuning and dynamic reconfiguring.

B I B L I O G R A P H Y

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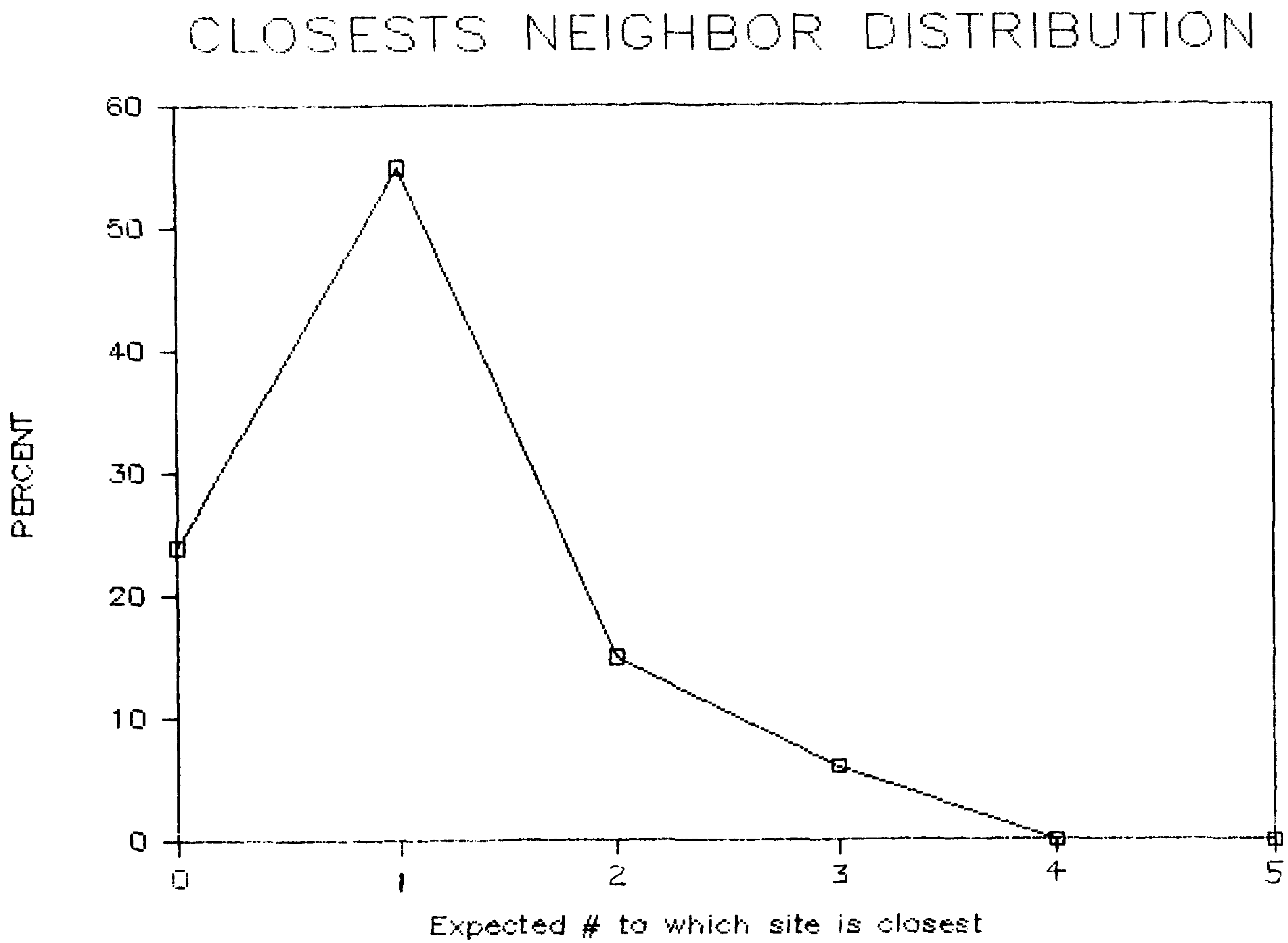
CLOSESTS NEIGHBOR DISTRIBUTION
60
50
40
30
20
10
0
PERCENT
0
1
2
3
4
5
Expected # to which site is closest

```
   {***********************************************}
   {* PROGRAM TO SIMULATE USE OF CLOSEST NEIGHBOR *}
   {*            AS A BACKUP CRITERION           *}
   {*                                             *}
   {* WRITTEN JULY, 1984                          *}
   {* BY DONALD A. VARVEL                         *}
   {***********************************************}

Program Neighbor_Simulation (Input, Output);
Const Max_Points = 200;             { Arbitrary; may be changed }

Type
   Point    = Record X, Y : Real End;
   Neighbor = Record P2 : Integer; Distance : Real End;
   Close    = Array[1..Max_Points] of Neighbor;

Var
   Plotter : text;                  { The plotter }
   Layout : Array[1..Max_Points] of Point;
                                    { The set of randomly-generated points }
   Closest : Close;                 { Array of closest neighbor and distance }
   Stats : Array[0..5] of Integer;  { Results of simulation }
   N : Integer;                     { Actual number of points; input }
   I, J : Integer;                  { Loop control, subscripts }
   Seed : Integer4;                 { Random number generator seed }
   HoldDist : Real;                 { Temporary place for distance }
   Count : Integer;                 { Accumulates occurances for Stat }
   Present : Integer;               { Holds present P2 value for Stat }
   Flag : Boolean;                  { Flow-of-control crutch }
   Y_OR_N : Char;                   { Reply from keyboard }


   { Function to compute Cartesian distance }
   { between two points P1 and P2.  The     }
   { extraction of the root has been        }
   { omitted in the interests of execution  }
   { speed, since it does not affect order. }

Function GEODESIC(P1, P2 : Point) : Real;
Begin
   GEODESIC := SQR(P1.X-P2.X) + SQR(P1.Y-P2.Y)
End;


   { Generate uniform random numbers in the }
   { range 0.0 <= R < 1.0                   }

Function RANDOM(Var Seed : Integer4) : Real;
Const BigNum = 25997;
      Modulus = 32768;
Var
   B : Boolean;
Begin
   Seed := (Seed * BigNum) mod Modulus;
   RANDOM := FLOAT4(Seed) / 32768.0
End;


   { Shell sort, by P2 ascending.  Initial }
   { distance is chosen by what appears    }
```

```
   { to be an arcane method, but which     }
   { gives good results.                   }

Procedure SORT(Var Tosort : Close; N : Integer);
Var
   Dist : Integer;
   I, J : Integer;
   TempP2 : Integer;
   TempDist : Real;
Begin
   Dist := TRUNC(EXP(LN(2)*TRUNC(LN(N)/LN(2)))) - 1;
                                     { 2^m - 1, where 2^m <= N:        }
                                     { Known good choice for Shellsort D }
   While Dist>0 do begin
      For I:=1 to N-Dist do begin
         TempP2 := Tosort[I+Dist].P2;
         TempDist := Tosort[I+Dist].Distance;
         J := I;
         While TempP2 < Tosort[J].P2 do begin
            Tosort[J+Dist].P2 := Tosort[J].P2;
            Tosort[J+Dist].Distance := Tosort[J].Distance;
            J := J - Dist;
            If J < 0 then Break
         End;     { While TempP2 ... }
         Tosort[J+Dist].P2 := TempP2;
         Tosort[J+Dist].Distance := TempDist
      End;     { For I ... }
      Dist := Dist div 2
   End      { While ... }
End;


Begin       { Main Program }
                                     { Get input parameters }
   Repeat
      Write('Enter number of points, <= ', Max_Points:1, ': ');
      Readln(N)
   Until N <= Max_Points;

   Write('Enter random number seed. ');
   Readln(Seed);
   Seed := Seed mod 32768;           { Avoid overflow in RANDOM }

                                     { Random layout }
   For I := 1 to N do begin
      Layout[I].X := RANDOM(Seed);
      Layout[I].Y := RANDOM(Seed)
   End;     { For I ... }

                                     { Compute closest distances }
   For I := 1 to N do begin
      Closest[I].P2 := 0;
      Closest[I].Distance := 4.0;    { Actual distances < 2 }
      For J := 1 to N do
         If I<>J then begin
            HoldDist := GEODESIC(Layout[I], Layout[J]);
            If HoldDist < Closest[I].Distance then begin
               Closest[I].Distance := HoldDist;
               Closest[I].P2 := J
            End      { then ... }
```

```
      End      { then ... }
   End;     { For I ... }

                                    { Sort on P2 }
   SORT(Closest, N);

                                    { Generate stats }
   For I:=0 to 5 do Stats[I] := 0;
   For I := 1 to N do begin
      Flag := False;
      For J := 1 to N do
         If Closest[J].P2 = I then Flag := True;
      If not Flag then Stats[0] := Stats[0] + 1
   End;
   J := 1;
   While J <= N do begin
      Count := 0;
      Present := Closest[J].P2;
      Repeat
         Count := Count+1;
         J := J+1
      Until (J > N) or (Closest[J].P2 <> Present);
      Stats[Count] := Stats[Count] + 1
   End;     [ While ... }

                                    { Print stats }
   Writeln; Writeln;
   Writeln('Simulation run with ', N:1, ' points:');
   Writeln('Closest neighbor of     Frequency');
   Writeln('-------------------     ---------');
   For I:=0 to 5 do Writeln('      ', I:1, '            ', Stats[I]);

                                    { Output options }
   Repeat
      Write('Output to plotter? (Y/N) ');
      Readln(Y_OR_N)
   Until (Y_OR_N = 'Y') or (Y_OR_N = 'y') or (Y_OR_N = 'N') or (Y_OR_N = 'n');

                                    { Plotter output }
   If (Y_OR_N = 'Y') or (Y_OR_N = 'y') then begin
      Assign(Plotter, 'PRN:');
      Rewrite(Plotter);
      Writeln(Plotter, ';: EH A '); { Init, small chart, absolute locations }
      Writeln(Plotter, '300,400 D 300,1400 U 300,400 D 2000,400 U ');
                                    { Axes }
      Writeln(Plotter, '300,325 S13 0_ ');
                                    { Label origin }
      For I := 1 to 5 do
         Writeln(Plotter, 'A ', 300+300*I:1, ',', 450:1,
            ' R D 0,-50 U 0,-75 S13 ', I:1, '_ ');
                                    { X tic marks and labels }
      Writeln(Plotter, 'A 350,817 R D -50,0 U -100,0 S13 25_ ');
      Writeln(Plotter, 'A 350,1234 R D -50,0 U -100,0 S13 50_ ');
      Writeln(Plotter, 'A 100,1000 S13 %_ ');
                                    { Y tic marks and labels }
      Writeln(Plotter, 'P2 A ');
      For I := 0 to 5 do
         Write(Plotter, (I+1)*300:1,',',
           TRUNC(FLOAT(Stats[I]) * (1667.0 / N)) + 400:1,' M2+4 ');
      Writeln(Plotter);
```

```
                                   { Markers }
      Writeln(Plotter, 'P3 A 0,400 CG ');
      For I := 0 to 5 do
         Write(Plotter, (I+1)*300:1, ',',
            TRUNC(FLOAT(Stats[I]) * (1667.0 / N)) + 400:1, ' ');
      Writeln(Plotter, '2100,400 CS ');
                                   { Curve }
      Writeln(Plotter, 'Z ')       { Deselect }
    End
  End.
```

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